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DIFFERENTIATION BY DEFORMATION

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Introduction.—The deformation of an igneous mass during crystallization, with consequent separation of liquid from crystals, has frequently been suggested as a cause of variation of igneous rocks but the suggestion has apparently never received as detailed consideration as it warrants. That variation would result is obvious, but the full extent of its importance will not be realized unless one has an adequate picture of the far-reaching consequences that may follow from the separation of crystals and mother liquor. In another paper the writer has demonstrated the consequences of such separation in artificial melts and applied the results to natural magmas.[1] Emphasis was there placed upon gravity as a means of separation of crystals from liquid but the chemical consequences are identical whatever the means of separation. In certain respects, however, the consequences of separation by deformation may be distinctive and to these attention is directed in the present paper.[1]

Discontinuous differentiation.—Discontinuous variations, in particular, are not normally to be expected as a result of gravitative accumulation of crystals but discontinuity would appear to be a very likely consequence of deformation. This is especially true at a late stage of crystallization when deformation may cause a crushing of the crystal mesh with consequent closer packing of the crystals and onward movement of the interstitial liquid. At first thought it might seem that the liquid could not move without carrying the crystals with it but it may be pointed out that the break down of a crystal mesh is likely to be progressive and any area breaking down will in such circumstances be bordered by an area not yet affected. The residual liquid is, therefore, free to move into the interstices of the unaffected portion of the mesh and to drive ahead of it the liquid already there which may become a separate intrusive body or a distinctive portion of the same intrusive and of late consolidation. Elsewhere the writer has offered the suggestion that the common association of gabbro and granophyre is frequently capable of interpretation in this

manner and perhaps many other associations particularly where the differentiation is markedly discontinuous both chemically and spatially.

Monomineralic types as members of composite intrusives.—Differentiation as a result of settling of crystals and as a result of deformation are by no means mutually exclusive; indeed, it seems probable that in one case, in particular, deformation may step in to bring to completion a task begun by gravitative accumulation, namely, in the case of the production of monomineralic types of excessive purity. For anorthosites, by way of example, it is probable that, besides the sorting of plagioclase crystals by gravitative action, a squeezing out of the interstitial liquid may have contributed to their extreme purity in many cases. If the squeezing continued after a high degree of compaction of crystals had been obtained a clastic structure might be developed and the common protoclastic structure of anorthosite may perhaps be interpreted as evidence that a squeezing out of residual liquid has played an essential part in its production.

Monomineralic types as simple "intrusives."—Peridotite as a sill-like "intrusive" would appear to be capable of production by a somewhat similar combination of crystal settling and deformation. If the intrusive material was originally simply basaltic, if in early stages of crystallization the settling of olivine crystals to the floor was pronounced and if at this time deformation occurred such that in certain places the roof was down-warped the result might be that the whole width of the sill in these places would be occupied by peridotitic material. The down-warping of the roof at this early stage of crystallization might not only remove the supernatant liquid from above the accumulating olivine crystals but might be of sufficient vigor that the interstitial liquid of the peridotite should be largely expressed and a mass of typical dunite result. The mass of peridotite or dunite so formed would have all the ear-marks of an ordinary intrusive sheet and there would be no internal, textural evidence that it had not crystallized from a molten mass of sensibly its own composition though no peridotitic or dunitic liquid ever existed in that region. The formation of this peridotitic differentiate connotes the possibility, indeed the probability, of a complementary granitic differentiate which may be represented as one member of a composite sill in those parts of the sheet that have been widened during the deforming action. The association of peridotitic intrusives with composite intrusives of this type is rather common and merits examination on the part of field-workers with the above suggestion as to origin in mind. In the asbestos region of Quebec the peridotite (now serpentine) masses are described by those best acquainted with them in the field as synclinal sheets.[2] This designation together with the association of diabases, diabase breccia, and granitic intrusives, suggests that the region may furnish a concrete example of the origin of a sheet-like peridotite "intrusive" after the manner described above.

It seems possible that even a dike-like mass of basaltic magma if deformed at an early stage of crystallization, might give rise, in the portions that are constricted by deformation to a peridotitic mass, though probably not as readily as in the case of a sheet. The mutual approach of the walls necessitates a movement of liquid out of the intervening space but close to the walls there would be a certain amount of drag of the crystals resulting in some movement of liquid relative to crystals. The two marginal regions of concentration of crystals might be brought together and even crystal packing and the expressing of liquid might occur if the constriction were carried far enough. Thus might result a dike which, intersected at this particular point, would be simply a peridotite. It would, therefore, seem necessary to include the above action among those to be considered as capable of producing dike "intrusions" of peridotite.

Complementary dikes.—Those minor but rather constant associates of intrusive masses, the complementary dikes, aplitic and lamprophyric, may perhaps be produced by action of the same general nature as that we are now considering. In very late stages of crystallization residual liquid may be drained into clefts in the mass and there suffer differentiation as a result of local pinching and swelling during crystallization. This is particularly likely to have important effects in such small bodies. Complementary units would be formed that might readily have a composition not matched in large intrusive masses.

Primary banding.—A further effect of deformation during crystallization appears to be that which finds its expression in primary banding. Shearing of a crystalline mesh, particularly when it is still weakly knit together and permits passage of liquid through it with great freedom, may develop a feature of the same general nature as a shear zone developed in solid rocks. Lenticular openings may be formed that instantly fill with liquid from the interstices of the mesh and repetition of the action may give rise to a banding, properly oriented with respect to the shearing stress, and showing approximately that contrast between bands that obtained between liquid and crystals at the time of the action. The crystals that became detached during the shearing would naturally become aligned in the liquid filling the lenses so that fluxion structure would be a natural accompaniment. Moreover, in the larger lenses developed a gravitative sorting of these detached crystals would take place under particularly favorable conditions and bands showing the extreme contrast of monomineralic types might thus be formed. The banded gabbros exhibit features that appear to match the results of the postulated action. Other rock types should be subject to similar action, but are probably not as likely to give such obvious contrasts in the bands as are the gabbros.

Alkaline rocks.—In rare instances rocks are found that have empty interstices and to these the term miarolitic is applied. It is usually assumed in explanation that the rock had crystallized in such a way as to

leave only gas as interstitial material. This is, however, not the only possibility. It is not difficult to conceive of a distribution of forces in the heterogeneous surroundings of an igneous mass such that locally the liquid might be sucked out of a crystalline mesh, which would acquire a miarolitic texture, temporarily, at least. The consequences of this action would normally differ in no essential particular from those produced by simple squeezing out of the liquid. It is probable, however, that this sucking action could be operative at a very late stage of crystallization when squeezing out of liquid may be impossible or at least very unlikely. The kinds of liquid that form some of the alkaline rocks may perhaps be removed in this manner from quartz-mica rocks at a very late stage of their crystallization and possibly only such action can effect the separation of these liquids. In certain regions of the earth's crust where tangential extension is the dominant expression of the forces acting (Atlantic structures) the development of alkaline rocks might be a prominent feature though the conditions requisite to their formation would undoubtedly occur locally elsewhere.

[1] The Later Stages of the Evolution of the Igneous Rocks, *J. Geol.*, **23,** 1915, Suppl., pp. 1–91.

[2] Howie, Robt., Summary *Rept. Geol. Survey Can.*, 1916, Coleraine Map Sheet insert, p. 228; also Knox, G. K., *Ibid.*, p. 229, et. seq. Reference is made to granitic "batholiths" in the anticlines, p. 232.

THE EVIDENCE FOR THE LINEAR ORDER OF THE GENES

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Despite Castle's dictum that we "have failed in two different attempts to establish the linear theory in the case of the three genes yellow, white and bifid," we are bold enough to maintain that the data furnished, and still furnish, the proof called for. We wish to call attention to the fact that in his last paper Castle ignores our proof of the linear order that is furnished by building up the whole chromosome (or even large sections of it) by "distances" so short that no double cross-over classes appear.

Castle asserts that we have rejected "nearly 99 per cent" of our data in the construction of the yellow, white, bifid section of the map. As a matter of fact no data have been omitted. In this case, as always, the order of the loci was determined by experiments that involved all of these loci at once. The order having been established the next step was to determine the relative distance between the loci by the use of all the available data. We have emphasized in our reply to Castle that there are several sources of variability in linkage values such as age, temperature, genetic factors. The variability due to these causes far outweighs that due to random sampling. It is, therefore, inadmissible to compare data from different